EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS, VOL. 26, 877–878 (1997)

AUTHORS' REPLY BY A. Y. J. WON[1], J. A. PIRES[2]* AND M. A. HAROUN[3]

[1]*United States Air Force Academy, Colorado Springs, CO 80840, U.S.A.*
[2]*Applied Research Associates, Inc., 4300 San Mateo Boulevard NE, Suite A-220, Albuquerque, NM 87110, U.S.A.*
[3]*Department of Civil and Environmental Engineering, University of California, Irvine, CA 92717, U.S.A.*

The discussers address, essentially, the following five points: (1) for systems with natural vibration frequencies close to the dominant frequencies of the ground motion, the effectiveness of the damper decreases when the degree of non-linearity in the response of the primary structure increases; (2) the response reduction achieved is very sensitive to the tuning ratio; (3) an authors' comment in p. 1270 of the article; (4) the damping values considered in the article for the primary structure are small as compared to those used to estimate the response of civil engineering structures to moderate earthquakes; and (5) the need for cost-benefit studies to assess the performance of passive dampers.

It is the opinion of the authors that items (1) and (5) above are related. The authors concur with the discussers that life-cycle cost-benefit analysis should be performed to assess the performance of passive tuned dampers. Such studies may show that the additional cost of the damper can be offset by the increased structural damping and the subsequent reduction in damage related loss under moderate earthquake loading and, according to the results presented by the discussers, a still significant structural response reduction under stronger earthquake loading. In this regard, cost-benefit studies for structural systems with control have also been suggested by others.[1] General methodologies for life-cycle cost-benefit analysis of buildings under earthquake loading are also available[2,3,4] which can be extended for buildings with control.

The discussers indicate that the effectiveness of the damper decreases rapidly when it is not perfectly tuned to the structure. In particular, they indicate that the response reduction ratio increases from 0.50 to 0.56 for a $\pm 5\%$ change in the tuning ratio. This sensitivity of the effectiveness of the damper to the uncertainty in the natural frequency of the primary structure does not appear to be a major impediment to its use and can be accounted for in the design process in a manner similar to that illustrated by the discussers. Different damper details may also be used which reduce its sensitivity to the tuning ratio. One such possibility may be, e.g. to use multiple dampers with closely spaced frequencies centered about the expected frequency of the primary structure and such that the sum of their masses is equal to the mass of the single damper.

The authors' comment on p. 1270 that is quoted by the discussers is made with the same purpose as the following comment in p. 1266; "For this example, the structural response reduction is essentially a result of the tuned mass damper effect, because of negligible structural response change when the mass of the TLCD is added to the mass of the structure". This comment and that quoted by the discussers are intended to express the fact that, under the narrow-banded loads considered, the structural response reduction is not significantly affected when the mass of the damper is rigidly attached to the primary structure and, therefore, this structural response reduction can be attributed to the tuned mass damper effect as reiterated by the discussers.

In regard to the damping values assumed for the primary structure it is recalled that damping values for flexible structures may not be always as large as those typically used to estimate the response of civil engineering structures to earthquake loading. The need to augment the damping for tall buildings under wind loading has, in fact, been well-documented. The low damping of a mid-rise building can also be

* Correspondence to: J. Pires, Applied Research Associates, Inc., 4300 San Mateo Boulevard NE, Suite A-220, Albuquerque, NM 87110, U.S.A.

CCC 0098–8847/97/080877–02$17·50

Received 18 March 1997

observed in building acceleration response records obtained during the 1989 Loma Prieta earthquake which reveal a very long free-vibration response with slowly decaying amplitude.[5]

REFERENCES

1. Y. K. Wen and A. H.-S. Ang, '*Reliability and cost-effectiveness of structures with control*', *Intelligent Structures—2*, *Monitoring and Control*, Elsevier, Amsterdam, 1992.
2. A. H.-S. Ang and D. De León, 'Determination of optimal target reliabilities for design and upgrading of structures', in *Proc. 11th World Conf. on earthquake engineering*, Acapulco, Mexico, edited by Sociedad Mexicana de Ingeniería Sísmica, Pergamon, Oxford, 1996.
3. J. A. Pires, A. H.-S. Ang and J.-C. Lee, 'Target reliabilities for minimum life-cycle cost design: application to a class of R. C. frame–wall structures', *Proc. 11th world conf. on earthquake engineering*, Acapulco, Mexico, edited by Sociedad Mexicana de Ingeniería Sísmica, Pergamon, Oxford, 1996.
4. J.-C. Lee, 'Reliability-based cost-effective aseismic design of reinforced concrete frame-wall buildings', *Ph.D. Dissertation*, University of California Irvine, California, 1996.
5. A. Shakal, M. Huang, M. Reichle, C. Ventura, T. Cao, R. Sherburne, M. Savage, R. Darragh and C. Peterson, 'CSMIP strong-motion records from the Santa Cruz Mountains (Loma Prieta) earthquake of October 17, 1989', *Report OSMS 89-06*, California Department of Conservation, Division of Mines and Geology, 1989.